“Like Popcorn”: Crossmodal Correspondences Between Scents, 3D Shapes and Emotions in Children

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ABSTRACT

There is increasing interest in multisensory experiences in HCI. However, little research considers how sensory modalities interact with each other and how this may impact interactive experiences. We investigate how children associate emotions with scents and 3D shapes. 14 participants (10-17yrs) completed crossmodal association tasks to attribute emotional characteristics to variants of the *“Bouba/Kiki”* stimuli, presented as 3D tangible models, in conjunction with lemon and vanilla scents. Our findings support pre-existing mappings between shapes and scents, and confirm the associations between the combination of angular shapes (*“Kiki”*) and lemon scent with arousing emotion, and of round shapes (*“Bouba”*) and vanilla scent with calming emotion. This extends prior work on crossmodal correspondences in terms of stimuli (3D as opposed to 2D shapes), sample (children), and conveyed content (emotions). We outline how these findings can contribute to designing more inclusive interactive multisensory technologies.

CCS CONCEPTS

• **Human-centered computing** → **Laboratory experiments**; **Empirical studies in HCI**.

Figure 1: 3D printed models of the “Bouba” and “Kiki” tangible stimuli used in the crossmodal association tasks.

KEYWORDS

Multisensory Interaction, Crossmodal Perception, Smell, Touch, Emotions, 3D Printing, Bouba, Kiki

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1 INTRODUCTION

Unlike our everyday experiences in the physical world, the senses we use to interact with digital technology are typically limited to sight, hearing, and to an increasing extent, touch. The potential of other, so called chemical senses [84], such as smell and taste, as modalities of interaction continue to be far less explored in HCI [63]. Yet, interest in multisensory HCI is steadily growing, with efforts to go beyond graphics and audio and tactile feedback and to bring smell and taste to the forefront of human-computer interaction (e.g. [23, 28, 74, 78, 86]). This is critical because augmenting interactive technologies with more sophisticated multisensory capabilities captures the richness of human experience and thus can lead to better designs of interactive technology. However, in order to do this properly, i.e. to combine multiple sensory modalities into effective multisensory experiences, we need to increase our understanding of how different sensory modalities relate to one another and influence each other. This understanding can be grounded in the study of crossmodal interactions [83]; the phenomenon where the signals we receive through one sense influence how we perceive and interpret signals received through another sense. As a basic example, consider our ability to associate the sound of a voice with the right speaker by, among other things, matching sounds to lip movements. At a more fundamental level, research on crossmodal perception has unravelled varied and deeper crossmodal interactions between the senses; for example, that the sounds we hear can influence our judgement of object size and elevation angle [9, 66], that visual patterns can influence linguistic judgements [49], that odour pleasantness shifts visuospatial attention [75], and that the colours we perceive influence the flavours we taste [71]. These crossmodal "principles", mainly the product of experimental psychology research, are not fully explored in HCI, and yet can have a tremendous impact on the design of interactive experiences [59]. As a research community, we are still lacking in our understanding of crossmodal principles and how they influence designing interactions with technology in practice.

In order to contribute to addressing these gaps, in this paper we present an exploration of crossmodal correspondences between scent, touch and emotions and reflect on the extent to which this could inform the design of inclusive multisensory technology. In particular, we aimed to explore how we can extend the *"Bouba/Kiki"* paradigm – a typically audio-visual paradigm of crossmodal interaction [73] – to the realm of smell and touch, and to investigate crossmodal correspondences between scent, 3D shapes and emotions in children. The wider context for this experiment is the goal of designing interactive educational technologies for visually impaired and sighted children that afford richer and more inclusive and engaging multisensory experiences. As a first step, we focus solely on sighted children in this paper.

We conducted a controlled experiment with 14 sighted participants between the ages of 10 and 17 years old who completed two crossmodal association tasks; a scent to touch association task; and a scent to touch to emotional content task. We used basic scents that have previously been shown to correspond to the visual stimuli of *"Bouba"* (vanilla) and *"Kiki"* (lemon) [42], and explored the extent to which children associate these smells with tangible 3D models of these stimuli. We also explored the extent to which these associations influence emotional associations, which we captured through a modified version of the self assessment manikin [11]. Whilst not significant, our findings seem to support pre-existing mappings between shapes and scents, and confirm the associations between the combination of angular shapes (*"Kiki"*) and lemon scent with arousing emotion, and of round shapes (*"Bouba"*) and vanilla scent with calming emotion. This extends prior work on crossmodal correspondences in terms of stimuli (3D as opposed to 2D shapes), sample (children), and conveyed content (emotions). In this paper, we contribute novel knowledge of how some scents are perceived alongside tangible sensory information. We outline how these findings can contribute to designing richer and more inclusive interactive multisensory technologies, and help to map out the space of crossmodal correspondences in HCI. We also contribute new accessible research methods for conducting research on crossmodal interaction.

2 BACKGROUND

Multisensory Interaction

Multisensory interaction in HCI considers the integration of a wider range of the human senses to design interactive experiences [61]. Multisensory interaction has the potential to enrich experiences across a wide range of domains, including education [60], entertainment [53, 74, 87], and accessibility [2, 17, 23]. But there are a number of challenges associated with designing and evaluating multisensory experiences in HCI. In a seminal work, Oviatt [64] discussed the misconceptions surrounding the potential of combining multiple sensory modalities to interface with computers. They emphasised the need for guidance from cognitive science in order to exploit the coordinated human perception and production of natural modalities for the successful design of interactive systems. Recently, Obrist *et al* [61] suggested the need to address challenges that include; how to determine which sensory experiences we can design for and how to stimulate them in people; how to build on previous frameworks for multisensory design and create new ones; how we should take into account the relationships between the senses; and how to account for perceptual limitations when users engage with multiple sensory modalities simultaneously. In this work, we aim to contribute to addressing the challenges of exploring and building on existing frameworks of crossmodal correspondences, informed by studies of crossmodal interaction and perception, and to examine how the sensory modalities of touch and smell relate to one another and interact with each other to influence emotional judgements.

Crossmodal Interaction

Crossmodal interaction underlies the phenomenon by which signals from one sensory modality can affect the processing of information perceived through another modality. One famous example of this phenomenon is the "McGurk" effect [57] where the auditory phoneme "ba" is perceived as "da" when paired with the visual stimuli of lips movements pronouncing "ga". The ideas behind crossmodal interaction stem from advances in cognitive neuroscience, specifically new understandings of brain plasticity and sensory substitution, which refer to the capacity of the brain to replace the functions of a given sense by another sensory modality [5]. Interest in the study of these types of crossmodal interactions between sensory information, and their implications for user interface design is emerging. For instance, Ju-Hwan and Spence [52] demonstrated that the presentation of sounds can modulate the number of vibrotactile targets that a person will perceive. Shams *et al.* [79] showed that people's perception of flashing lights can be manipulated by sounds, with people seeing a single flash of light as consisting of two flashes when these are presented simultaneously with multiple auditory beeps. Sensory modalities are therefore far from working as independent modules, and findings from these and similar studies challenge the notion that their interaction follows a hierarchy in which vision dominates the sensory experience. In the context of this paper, this suggests that different tactile and olfactory mappings can influence perceptions of emotional characteristics and that different combinations can yield more natural correspondences.

Crossmodal Correspondences. The terms *congruence* or *crossmodal correspondences* are often used to refer to non-arbitrary associations that exist between different modalities. For instance, studies found crossmodal correspondences between high-pitched sounds and bright, small objects positioned at higher locations in space, and between low-pitched sounds and darker, bigger rounder objects at lower locations [9, 66]. Other studies found congruent mappings between pitch and vertical location, size and spatial frequency [32]. In the realm of HCI, a number of researchers have demonstrated the benefits of exploiting crossmodal congruency for better user interface design. Hoggan and Brewster [45], for instance, showed that perceived quality of touchscreen buttons was correlated to congruence between visual and audio/tactile feedback used to represent them. Finnegan *et al.* [35] showed how using incongruent audio-visual display can improve the perception of distance in virtual environments. Metatla *et al* [59] demonstrated how a congruent audio-visual display can result in better performance and higher engagement in game play involving estimation of vertical elevation. And Azmandian *et al.* [4] leveraged sensory information conflicts to improve alignments of physical and virtual objects.

Correspondence between smell and touch and shapes. Of particular interest to the questions we explore in this paper are crossmodal correspondences between various sensory modalities and shapes. Ramachandran and Hubbard [73], found that between 95% and 98% of the population agree on which of the shapes in Figure 2 is *"Bouba"* (right) and which is *"Kiki"* (left). Most recently, correspondences between shapes and specific odours were identified [42], where

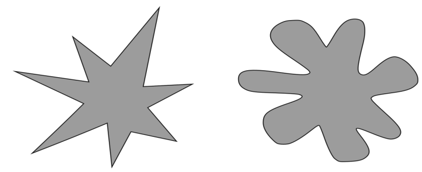

Figure 2: 95% to 98% of the population agree that "kiki" is the shape on the left and "bouba" is on the right [73].

specific odours are significantly associated with either angular (lemon and pepper) or rounded shapes (raspberry and vanilla). Previous work has also shown that the presence of an odour can modify the tactile perception of fabric softness [25]. In the present experiment, we aim to extend this line of research on crossmodal correspondences between smell and touch in terms of stimuli (3D as opposed to 2D shapes), sample (children), and conveyed content (emotions). More specifically, we aim to examine the extent to which the existing audio-visual crossmodal *"Bouba/Kiki"* paradigm can be translated to smell and touch, and to test this with children. The experiment therefore builds on previous work on crossmodal perception that demonstrated congruence effects between visual and linguistic features [73], as well as prior work on crossmodal emotional associations, which show that emotional attention can operate across sensory modalities (e.g. [15]).

Emotions, Touch and Smell

Emotion plays an important role in our everyday interactions with people and increasingly through technology. Although emotion theory is not grounded in HCI, there have been a number of fundamental studies on affective computing that have increased awareness of the important role emotions play in HCI and multisensory interaction [68–70]. Emotions are primarily elicited by stimuli received by our senses [40]. Although, crossmodal correspondences have been extensively studied (see [82] for a review), their effects on our emotions have limited focus (e.g., [20]). The impact of crossmodal correspondences on emotions seem to be explained mainly by the emotional congruency effect (emotional crossmodal transfer [55]), amplifying an emotional reaction when two or more sensory stimuli are in the same emotional domain (e.g., same valance or same arousal). One of the best-known models for measuring emotions has suggested looking at emotions in terms of two dimensions: valence (i.e., positive and negative) and arousal (i.e., high and low) [51]. This model provides a simplified view of the circumplex model [7] by just focusing on the extremes (i.e., valence and arousal axes) [33], overcoming biases related to the introspective verbalization of emotions in self-report measurements. The emotion dimensions are best captured with the Self-Assessment Manikin (SAM) [11], an affective rating system that not only includes valence and arousal but also a third dimension, dominance (the feeling of being in control or controlled). To assess those dimensions, the SAM uses graphic figures depicting the different values on the scale that indicate the emotional reactions. In HCI and cognitive sciences we can find databases of standardized stimuli eliciting specific emotional reactions, however the stimuli used are always unimodal (e.g., auditory [12], visual [50], or haptic [62]) and only recently a database was extended to multimodal emotional stimuli [39] but not with concurrent presentation. There has been recent work that examined the impact of concurrent sensory presentation on emotion. For example, Akshita *et al.* explored how emotional cues presented in visual and haptic modalities interact and showed that the presence of a haptic stimulus affects the arousal of the visual stimulus without affecting valence [1]. The present work contributes to extending this particular line of research by assessing the emotion elicited by the concurrent touch and smell explorations.

The sense of smell, despite having captured the interest of scientists and philosophers for centuries and its close relationships with the limbic system and emotion [93], has only recently started to be investigated as an interaction modality in the field of HCI. This is in part due to the complexity of our sense of smell, both physiologically and psychologically, which, for example, makes it difficult to create a rigorous, systematic, and reproducible classification scheme for smell [48]. But also due to the difficulty in producing technology for the digital delivery of scents. Not surprisingly, then, initial efforts in HCI have been focused on developing experimental prototypes to allow for scent delivery. Examples include the OSpace [28], Olfoto [14], and the SensaBubble [78]. There is also recent work that considers using smell as a modality for design [23, 46, 60], in-car navigation [29], and ambient notification (e.g., [10, 54, 90]) In the midst of these challenges and advances in olfactory display in HCI, communicating emotions continues to be a challenge, especially when considering doing so through the combination of touch and smell. We therefore need to increase our understanding with regards to how sensory modalities interact to deliver emotional content, and how we interpret emotional content on the basis of input from multiple sensory modalities.

3 EXPERIMENT

The aim of the present experiment is to explore children's tendencies to associate 3D printed shapes with scents in the context of crossmodal and emotional association tasks. In a similar approach to Gallace et al. [38], who examined the *"Bouba-Kiki"* effect in the context of crossmodal word-food associations, we aim to explore the extent to which crossmodal associations between scents, 3D shapes and emotions are present independently of vision.

Tasks

Crossmodal associations task. Following a within-participants design, all the participants evaluated the associations of 3 scent stimuli (i.e., air, vanilla, and lemon) with 3D shapes (i.e., Bouba, Kiki, Cylinder shapes - Figure 1), for a total of 18 randomly presented trials (3 scent stimuli x 3 shapes x 2 repetitions). The trials were also randomized based on a Latin square.

Emotional associations task. Following a within-participants design, all the participants evaluated the emotional associations of 2 scent stimuli (i.e., vanilla and lemon) combined with 3D shapes (i.e., Bouba, Kiki, Cylinder shapes) for a total of 12 randomly presented trials (2 scent stimuli x 3 shapes x 2 repetitions). The trials were randomized based on a Latin square. The experiment lasted about 30-40 minutes, approximately 15 minutes for the crossmodal associations task and 10 minutes for the emotional association task, with a 5 minute break in between the two tasks, and a 5 minute interview at the end of the session, in which participants were asked about their strategies and rationale for associations, if any. The presentation of the two tasks were randomized to avoid any order bias. Ethics approval for the experiment was obtained from the University's Ethics Committee.

Participants

A total of 14 participants (10 female and 4 males) between the ages of 10 and 17 years old (M=14.4, SD=2.16) volunteered for this experiment. They were recruited through a local school and open days at the authors' university. Participants' care-givers signed a consent form before the experiment, in which it was reported that none of the participants had any olfactory dysfunctions or allergies.

Apparatus

Scent-delivery device and scent stimuli. For controlling the presentation of the scent stimuli in the crossmodal associations task we used a custom-built scent-delivery device (see Figure 3), which is a portable version of similar devices used in previous work [28, 54]. The clean pressurised air splits into individual channels, each passing through an electro-valve and arriving at one of the small glass bottles (three in this set up) that contain the scent stimuli (i.e., natural essential oils, off-shelf products[1]). The air supply pressure for the device can be set to a constant supply value between 0.5 and 3 Bar through an air regulator. The output of scented air reaches the participant through a 3D-printed merging nozzle (output

[1]Purchased from from Holland and Barrett.

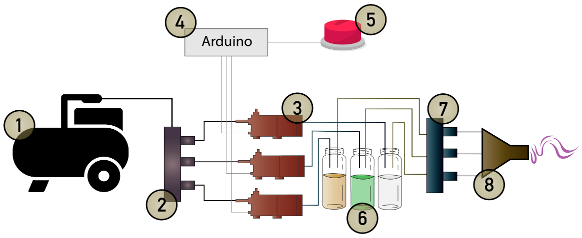

Figure 3: Scent-delivery device visualisation, (1) air-compressor, (2) air-filters, (3) electric valves, (4) Arduino board, (5) button, (6) glass bottles with the scents, (7) one-way valves, (8) output 3D printed nozzle.

diameter 1.5mm). The nozzle was positioned at 45cm [54] from the participants. We selected lemon and vanilla scents because they are associated respectively with angular and round shapes [42]. The scent stimuli were 2.5g of vanilla and lemon essential oils and water, in the case of the neutral condition of air. The participants activated the scent-delivery by pressing the button (see Figure 4). The delivery lasted for 2.5s at a constant pressure of 1Bar, with a forced break time between button pressing of 10s.

In the emotional associations task, we presented the scent stimuli using two numbered jars, one for each scent (i.e., vanilla and lemon). The participants were asked to lift and smell the scent jar following the experimenter's instruction, meanwhile exploring the shape positioned in the box with their dominant hand. In this task, the duration of the scent stimulus presentation was not controlled, in order to leave the participants the freedom to perceive the scent and tactilely explore the shape as long as necessary (varying between 4-8s).

3D shapes stimuli. We 3D printed tangible models of three shape types (Figure 1). Two shapes were designed to mimic Köhler's *"Bouba"* and *"Kiki"* traditional visual shapes ([37]). A third shape was designed to extend the crossmodal correspondences to a non-traditional shape with geometrical features not clearly definable as angular or rounded (i.e. a possible neutral shape). The 3D shapes were printed using PLA (Polylactic Acid) filament, with a dimension respectively of *"Bouba"* 60x60x40mm, *"Kiki"* 65x62x40mm, *"Cylinder"* 32x32x35mm. To present the 3D shapes for tactile exploration while occluding the vision, 2 wooden boxes (dimensions 20x15x15cm) were cut and assembled. All the elements in the set-up were covered with the same fabric material to avoid possible bias or distraction due to materials or colour differences (Figure 4).

Procedure

Participants were seated comfortably on a chair facing the scent-delivery device nozzle, a 3D printed ruler (see below)

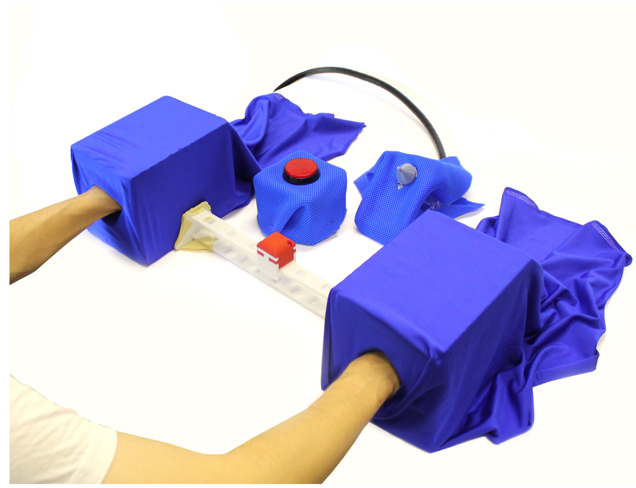

Figure 4: Experimental setup

was positioned in front of them between the two boxes in which the 3D shapes were presented for exploration (see Figure 4). The shapes were placed by the experimenter in the boxes following the randomization procedure and were covered by a cloth, so participants were unable to see which shape was used in each trial. The participants were verbally instructed to press the red button and position their hands in the two boxes to explore the 3D shapes (one in each box). They were instructed to explore the objects without lifting them from the base of the boxes. After the tactile exploration the participants were asked to rate which of the two objects the scent was more associated with, by moving the red cursor along the ruler. The experimenter recorded the position of the cursor on a printed sheet. After the responses were recorded, the experimenter positioned the next set of shapes, reset the cursor, and the participants were informed to proceed with the next trial. After a short break, participants were presented with a combination of one shape and one scent stimulus and asked to evaluate the emotional associations. The evaluation was made verbally between 3 choices for each emotional dimension and recorded by the experimenter. The shape and scent combinations were presented following the randomization procedure and administrated by the experimenter.

Crossmodal associations task. We measured the associations between scent stimuli and 3D shapes using a scale with 7 discrete points, presented on a physical ruler. The ruler was 3D printed with a slider (4x4x4cm) that can move left and right along the length of the ruler (36cm). The slider had a red ball and spring underneath to provide a haptic sensation and an audible "click" at 7 discrete points evenly spaced along the ruler.

	Air	Vanilla	Lemon
Bouba	3.40 (1 to 3)	3.80 (2 to 5)	3.40 (1 to 4)
Kiki	3.30 (2 to 3)	2.70 (1 to 4)	4.60 (3 to 6)
Cylinder	3.20 (2 to 4)	3.20 (2 to 5)	2.80 (2 to 4)

Table 1: Participants' medians (IQR) of associations between 3D printed shapes and scents.

Emotional associations task. We measured the emotional associations with the combination of scent stimuli and shapes through an audio pre-recorded questionnaire. The questionnaire measured the three emotional dimensions commonly used in the Self-Assessment Manikin (SAM) [11] (i.e., valence, activation, confidence) on a 3-point Likert scale with a verbal answer recorded by the experimenter on a pre-printed sheet. We used three audio-recorded questions: *"Does the combination of the fragrance you are smelling and the shape you are feeling give you a sense of?"* with the three possible answers for valence (*happiness*, *neutral*, *sadness*), activation (*calmness*, *neutral*, *excitement*), and confidence (*confidence*, *neutral*, *uncertainty*).

The measures were selected to reduce visual bias given our aim to explore if the crossmodal associations between shapes and scents are independent of vision. For this reason we did not select the traditional visual analogue scale for the crossmodal association task and the traditional SAM for the emotional association task. The experimental procedure can also be applicable to a different sample (e.g., visually-impaired children).

Interviews. Participants were interviewed at the end of the session. The experimenter asked general questions to elicit information about participants' strategies and rationales for associations, if there were any. Interviews were semi-structured, which allowed participants to discuss their experiences freely. Interviews were audio recorded.

Results

Crossmodal associations task. To explore the association frequencies between scent and shape types we performed a non-parametric test, Kruskal-Wallis H including post-hoc tests with Bonferroni correction [80]. We found no statistically significant differences between scent and shape associations. There is a trend in the direction of association of the vanilla scent with the *'Bouba'* shape and the lemon scent with *"Kiki"*. The neutral scent (i.e., air) is not clearly associated with any of the shapes (see Table 1).

Emotional associations task. To estimate the associated effect of scent stimuli and shape types on participants' emotions, we performed non-parametric tests (Friedman test) [80] on each of the emotion dimensions (i.e., valence, activation, and

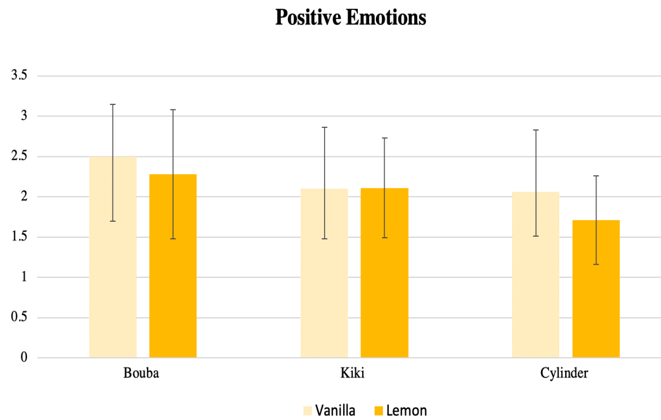

Figure 5: Mean scores of positive emotions associated with the combination of scent stimuli and shape types. (Error bars, ± s.e.m.).

Figure 6: Mean scores of arousing emotions associated with the combination of scent stimuli and shape types. Error bars, s.e.m., ** *p < .01*, *** *p < .001*.

dominance). To understand specifically in which condition of scents and shapes there are differences we ran post-hoc analyses with Wilcoxon signed-rank tests, with Bonferroni correction (resulting in a significant level set at $p < 0.006$).

1. *Valence.* There is a non-significant tendency ($p > 0.05$) on the valence values depending on scent and shape types, with the combination of *"Bouba"* with vanilla ($Mdn(IQR) = 2.75(2\ to\ 3)$) and with lemon ($Mdn(IQR) = 2.50(1.75\ to\ 3)$), the combination of *"Kiki"* with vanilla ($Mdn(IQR) = 2(1.37\ to\ 3)$) and with lemon ($Mdn(IQR) = 2(1.62\ to\ 2.66)$), the combination of *"Cylinder"* with vanilla ($Mdn(IQR) = 2(1.38\ to\ 3)$) and with lemon ($Mdn(IQR) = 2(1\ to\ 2)$) (Figure 5).
2. *Activation.* There are statistically significant differences on activation values depending on scent and

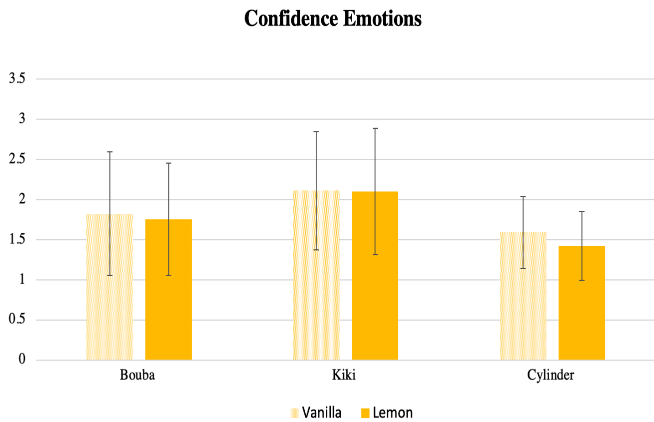

Figure 7: Mean scores of confidence emotions associated with the combination of scent stimuli and shape types. (Error bars, ± s.e.m.).

shape types ($\chi^2(5) = 32.89$, p < 0.001). In particular, between *"Kiki"* with lemon and *"Bouba"* with vanilla ($Z = -3.30, p = 0.001$); *"Kiki"* with vanilla and *"Cylinder"* with lemon ($Z = -2.84, p = 0.004$), *"Kiki"* with vanilla and *"Bouba"* with vanilla ($Z = -3.26, p = 0.001$). With the following values for the combination of *"Bouba"* with vanilla ($Mdn(IQR) = 1(1\ to\ 2)$) and with lemon ($Mdn(IQR) = 1.25(1\ to\ 2.13)$), the combination of *"Kiki"* with vanilla ($Mdn(IQR) = 2.5(2\ to\ 3)$) and with lemon ($Mdn(IQR) = 3(2.25\ to\ 3)$), the combination of *"Cylinder"* with vanilla ($Mdn(IQR) = 1(1\ to\ 2)$) and with lemon ($Mdn(IQR) = 1.5(1\ to\ 2)$) (Figure 6).

(3) *Confidence.* There are no statistically significant differences on confidence values depending on scent and shape associations. All the median confidence values are around 1.75 (IQR 1 to 2), but with the *"Kiki"* shape combined with vanilla and lemon scents we see higher median values (vanilla $Mdn(IQR) = 2(1.35\ to\ 3)$, lemon $Mdn(IQR) = 2(1.50\ to\ 3)$) (Figure 7).

Subjective Association Strategies. Audio recordings of interviews were transcribed. One researcher went through the transcripts and extracted general patterns from participants feedback about their association strategies and rationales. We conducted a light peer validation of this process, where we discussed and reviewed the emerging patterns and made grouping decisions.

Participants did not report a specific association strategy or clear rationale for the crossmodal association task. Some participants reported being unsure about how they would describe the rationale for their choices (n=8). This was particularly the case for the cylinder shape, where participants expressed not being able to associate the shape with any smell (n=5) or associating the shape with one of the smells that they felt they could not recognise or name (n=7). Interestingly, some participants (n=6) reported only detecting one smell at different intensities, which made it difficult to rationalise or make strategic association decisions.

A number of participants expressed more defined strategies for the emotional association task (n=10). We were able to group strategies into four seemingly interlinked and interdependent categories: **(1) Sense of pleasantness** where participants made emotional associations on the basis of which smells and shapes they found pleasant, e.g. *"a nice smell"*, *"it was sweet and nice"*, *"I like the feeling of the smooth surface"*; **(2) Personal connections** where emotional associations were made on the basis of personal memories of significant individuals and/or events, e.g.*"reminded me of grandma's garden and flowers where I used to go"*, *"the smell of my mum baking"*, *"reminds of the hospital room where my grandmother passed away"*; **(3) Connections to locations** where emotional associations were made on the basis of links to actual or imagined places, e.g. *"some of the smells I relate to somewhere I went to or somewhere I have been, like at home so easier to connect"*, *"reminds of my chemistry lab"*, *"like walking in the forest"*; **(4) Geometrical features** where emotional associations were made on the basis of direct reference to the geometric features of the shapes, e.g. *"spikes are happy and eccentric but also hard and piercing so kind of sad"*, *"round is calm because it's smoother to touch, but also uncertain because it too smooth, I didn't like it"*, *"spiky is confident, it's out there, cylinder is uncertain because it's all closed up on itself"*.

4 DISCUSSION

Grounded in the study of crossmodal interaction, the present experiment was designed to explore the kind of associations that children make between scents and tangible 3D models of shape stimuli, namely the angular (*"Kiki"*) and rounded (*"Bouba"*) shapes that have been classically used in studies of word-shape association [49]. The *"Bouba/Kiki"* effect is very well-documented in the literature; it describes non-arbitrary mappings between visual shapes and speech sounds, and has been demonstrated across a variety of contexts, including different cultures (e.g. [8, 13]) and age groups [56, 65]. As such, increasingly more attention has been directed toward researching possible perceptual interactions involving other senses than the original word-shape association, e.g. the effect has been extended to word-food associations [38]. Our present work thus falls within this line of research that examines alternative sensory interactions and crossmodal correspondences the *"Bouba/Kiki"* paradigm. In particular, we aimed to extend prior work by examining tangible representations of *"Bouba"* and *"Kiki"* in combination with scent stimuli. Our choice of scent stimuli was based on findings from prior research that identified links between specific odours associated with either angular (lemon and pepper) or rounded 2D shapes (raspberry and vanilla) [42]. The aim of the experiment was therefore to examine the extent to which these associations translate to tangible 3D models and to child participants, as well as to investigate the kind of emotional elicitation that can be achieved with concurrent presentation of scent and tactile stimulation, thus also extending prior work on multisensory elicitation of emotions [39]. This is the first study of its kind to examine a combination of tangible and olfactory form together with emotional elicitation of this crossmodal paradigm.

Shape/Scent crossmodal association

In relation to the crossmodal association task, our results showed that there are no statistically significant differences between the scent and shape types and therefore no clear tendencies to associate particular tangible shapes with particular scents. There was a trend in the direction of associating the angular shape (*"Kiki"*) with the the lemon scent and the round shape (*"Bouba"*) with the vanilla scent, and the neutral shape (*Cylinder*) yielding no clear association. Notwithstanding this tendency, our results seem to suggest that the *"Bouba/Kiki"* haptic-auditory associations [37] traditionally influenced by visual experience does not readily translate to experiences of smell and touch. It is of course possible that we did not observe the *"Bouba/Kiki"* effect because of the lack of visual conditioning since the original effect is driven by sound symbolism with visual shape. In our case we removed the basic components that elicit the effect, i.e. neither auditory nor visual information was present. It is therefore interesting to examine whether the same experimental procedure, with the exception of exposing the tangible objects to include visual inspection could yield different results.

Exploration strategies may also have influenced the results. Participants in our experiment did not report any specific or structured strategies or rationale for completing the crossmodal association task. Instead, they seem to have commonly relied on intuition, which may explain the lack of significant trends in their performance in this task. Another possible explanation for our findings is related to how some participants reported perceiving the scent stimuli. For some participants, the stimuli was as a single scent with different levels of intensity as indicated in the post-test interviews, which may have influenced overall perceptions and consistencies of associations.

Emotional association

In relation to the emotional association task, our results showed significant associations between the combination of angular shapes (*"Kiki"*) and the lemon scent with arousing emotion, and of round shapes (*"Bouba"*) and the vanilla scent with calming emotion. We thus observed significant emotional activation even in the absence of the visual experience of the 3D shapes. These findings align with prior research on odour/shape associations and integration of non-visual sensory information. For example, while some researchers (e.g. [77]) have argued that vision is essential to crossmodal integration, others, (e.g. [38]), have demonstrated the *"Bouba/Kik"* effect independently of vision. Fryer et al [37] also demonstrated the effect in the auditory-haptic modalities in fully sighted and visually impaired participants. In relation to emotional elicitation, our findings also align with recent evidence that suggests that crossmodal correspondences occur at both low-level amodal stimulus properties, such as duration, through to high-level cognitive correspondences based on stimulus meaning/valence [82]. Other work has shown that the duration and frequency of exposure to odours can affect emotional salience, for example, repeated presentation of a pleasant scent typically decreases perceived pleasantness and conversely, repeated exposure to an unpleasant scent decreases perceived unpleasantness [18, 22, 34]. However, in our context we made efforts to limit the effects of olfactory habituation by providing a "recovery period" of nine seconds between each scent stimuli delivery [67, 72].

The Sense of smell is highly complex and individual and it is important to take this into consideration when conducting olfactory research in HCI. Again, in post-test interviews, some participants reported only being able to identify one scent, rather than two. For these participants it is possible that some form of cross-adaptation effect took place, in which exposure to one scent can reduce sensitivity to another [67]. Often, this is more common with unfamiliar odours or scents that are considered similar [19]. In our experiment, in instances where a second scent was not detected, exposure to the stronger scent (lemon) may have led to reduced sensitivity of the vanilla scent, thereby causing participants to believe that only one scent was presented throughout the duration of the experiment.

It is also interesting to observe that our participants had much more definably expressed strategies for the emotional association task compared to the previous task. Here too, exploration strategies may have influenced the results we obtained. In particular, the four categories of strategies we extracted from analysing interview transcripts are in line with previous work showing emotions and scent connections where the emotion-eliciting effect of scents is typically linked to childhood memories [91] and is closely linked to specific events, places, people, and activities [63]. Research has also highlighted the difficulty of labelling scents, and that often the first two dimensions that are recognised — and that impact judgement — are pleasantness and intensity. Scents are also often described using attributes from other sensory modalities (e.g., sweet, bright, etc.) and geometrical shapes [24, 26, 47, 82]. One instance from our interview data captures these insights compellingly; after completing the experiment, P14 reflected: *"now that I think of it, if I was to describe something that smells, I can only describe whether it smells nice or smells bad, like popcorn you know, you know what the smell of popcorn is but you can't really describe it to someone, it just smells nice, but you can say how it sounds and how it looks, but not how it smells"*.

General Implications for Multisensory and Crossmodal Interaction

Overall, the approach followed here provides evidence for how to combine and use different modalities based on certain dimensions, like emotional or sensorial congruence. These findings could be applied to storytelling, for example, with different arousing levels associated with combinations of scent/shape stimuli which could be used to present different "activation" scenes. As an example, a relaxing story scene could be presented with "Bouba/Vanilla" stimuli, a more upbeat scene could use a "Cylinder/Lemon" combination, whereas a more exciting, high-arousing scene could be presented with "Kiki/Lemon" stimuli. There is increasing interest in the HCI community for using interactive, multisensory approaches in storytelling [23, 31, 89, 95], and we discuss one possible approach for multisensory storytelling with children with visual impairments in the section on *Accessibility and Inclusion* below.

This work begins to establish how crossmodal correspondences could be systematically explored for design. This can help to identify properties that could be used to classify shape/scent stimuli, and the extent to which emotions should be understood as essential or secondary contributors to crossmodal correspondence processes. Some of the work towards systematic exploration of the design space for multisensory or crossmodal design has already been explored elsewhere (eg. [43]), which looks at the use of established psychophysical approaches in beginning to unravel how multiple senses can contribute to more immersive and cohesive design. New research also shows how synesthetic and multisensory design approaches can be adopted for enhanced creativity [58], product design [81] and inclusive education [3].

Some examples of how these findings could be applied to the design of richer interactive multisensory experiences for creativity and education include augmenting tangible bits with olfactory display to explore photo applications, or tagging content in storytelling applications, (as detailed below); or the design of novel interactive devices (eg. a shape-changing mouse controller morphing into a Bouba- or Kiki-like shape to relay reassuring or disconcerting notifications). In inclusive education, shape/scent pairings could be embedded in tangible objects to support understanding of emotional states for young children and children with complex needs, providing more engaging sensory learning experiences. These findings thus open up new spaces for general systematic study and application of both multisensory experiences in HCI [61] and general principles of crossmodal correspondences, which could also be applied to other areas, for example improving engagement in mobile games [59] and immersion in virtual reality [21, 35].

Accessibility and Inclusion

Our findings highlighted associations between scents and shapes which are in line with pre-existing mappings, as well as significant associations of scent-shape combinations for eliciting emotions on the arousal dimension. These findings are of both theoretical and practical interest as they can inform more interesting and effective designs of olfactory interaction, particularly when combined with tangibles. One particular way we are pursing practical implications of these findings is to inform the design of multisensory interactive tangible technologies for storytelling for children with and without visual impairments. Children living with visual impairments are increasingly educated in mainstream schools alongside their sighted peers, rather than in special schools [76]. However, despite being included with their sighted peers, recent research has identified persistent issues with participation [88, 94], reduced opportunities for collaborative learning and social engagement [6, 36] and potential for isolation [60]. These challenges have been attributed in part to the technical support that children with VIs receive in mainstream schools. In particular, assistive learning technologies are often designed to be used by pupils with VIs alone and not by their sighted peers, and can therefore exacerbate the above issues [60].

Findings from the present experiment can be used to consider the extent to which principles of crossmodal correspondences can bridge the disconnect between the designs of educational technologies for visually impaired and sighted children. In one concrete example of this, we are exploring how we can embed richer and more engaging means for expressing emotional content in storytelling technologies. Schools use storytelling to promote and support children's understanding of story components (plot, structure, character, setting), and to help them with remembering and structuring the events of stories they are learning about in class. Storytelling can also support creative writing, which plays an important role in helping to develop children's meaning-making and sense making. However, the use of story mapping techniques in primary schools rely heavily on visual materials, where it functions as a graphic organisation method or visualisation tool to plan or map out story elements. Such a strong visual focus on framing group understanding of stories can compound problems of social and academic exclusion for children with visual impairments. Inclusive learning for children with visual impairments in mixed group settings is a largely under-researched area, and

Figure 8: Multisensory co-design workshop using tangible *"Bouba"* and *"Kiki"* and lemon and vanilla scent to tag emotional content onto stories

we are using findings from crossmodal association experiments together with storytelling and co-design as a starting point to explore this problem (Figure 8).

Additionally, the use of multiple modalities could be explored to extend accessible interactive maps for visually impaired users [17, 30]. Recent work has also shown the potential for translating graphical *"Bouba"* and *"Kiki"* into audio using sensory substitution devices (SSDs) [16], in which participants were presented with a tactile version of *"Bouba"* and *"Kiki"* and a soundscape version provided by a visual-to-auditory SSD. The authors found that participants who used the SSD were able to discriminate shapes through sound after only minimal training. Our findings could extend this research and other work on crossmodal display for accessible technology in the design of SSDs [41, 85], for example by augmenting audio-based SSDs with olfactory and tactile displays, and also contribute to the design of accessible technologies more broadly.

Finally, this work also contributes to the growing body of research on crossmodal correspondences in the sighted and visually impaired [27, 41], and we further contribute new accessible research methods, such as the verbal Self-Assessment Manikin (SAM), tactile *"Bouba"* and *"Kiki"*, and 3D printed slider with haptic and audio feedback, which can facilitate the inclusion of visually impaired participants in future crossmodal research.

5 FUTURE WORK

We aim to extend the results we obtained in the present experiment in two ways. First, we are in the process of replicating the above experiment with a sample of children living with visual impairments. Our experimental procedure is designed such that it readily allows for such replication and comparison, for example, the use of a physical ruler for expressing crossmodal associations, and audio-recorded SAM for reporting emotional elicitations. Second, we are conducting a series of co-design workshops, as outlined in the *Discussion*, to involve both children with and without visual impairments and their educators in the design of multisensory collaborative and inclusive technology for storytelling (Figure 8). We engage participants with mixed visual abilities in the design process through multisensory materials, including the tangible and olfactory stimuli explored in the present paper, and observe how they use them to embed emotional content in their stories; as a first step towards designing multisensory storytelling platforms. Future work will also embed tangible models with interactive capabilities, for example to display audio recording of character lines and story plots, to augment story scenes with multisensory feedback, including using interactive tangible and olfactory models of *"Bouba"* and *"Kiki"* characters, and to encourage joint story creation through multisensory playback.

Further Investigations. There are a number of potential modifications and avenues for further explorations that are entailed by our investigations. We could, for instance, speculate that using a tangible version of Self Assessment Manikin [44] with children may reduce potential bias that the experimental procedure may have introduced when capturing affective rating elicited by a tangible stimuli. Additionally, future studies could investigate the impact of the texture, weight and material of the 3D shapes (e.g. building on [25]), or their thermal profile (e.g. [92]) on crossmodal and emotional associations. Further ideas to explore include measuring individual preferences of both scents and shapes, extending the set of scents stimuli and introducing sounds symbolism, e.g. high and low pitch (e.g. [16]). From a procedural perspective, future work could consider implementing the ruler used for expressing crossmodal associations as continuum without forcing the positioning in pre-defied locations.

6 CONCLUSION

We presented the first exploration of the *"Bouba/Kiki"* crossmodal correspondence effect in a concurrent presentation of tangible and olfactory form. We examined the effect with children in crossmodal and emotional association tasks and found some evidence that supports pre-existing mappings, and confirmed the presence of crossmodal associations between angular shapes and the lemon scent with arousing emotion, and round shapes and the vanilla scent with calming emotion. These results extend prior work on crossmodal correspondences by increasing our understanding of how sensory modalities interact with and relate to one another. They also provide novel insights for informing the design of richer and more engaging multisensory experiences. On the basis of these results, we reflected on the wider context of supporting inclusive interactions between children who have mixed sensory abilities and described practical implications of our findings in these directions.

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